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### The costs of adoption of RFID technologies in supply networks

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# THE COSTS OF ADOPTION OF RFID TECHNOLOGIES IN SUPPLY NETWORKS

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## ABSTRACT

**Purpose:** To identify the different types of adoption costs faced by organizations involved in the adoption of RFID within supply networks, and to understand how these potential costs affect the likelihood of RFID adoption.

**Design/methodology/approach:** The paper applies an existing generic theoretical framework of costs associated with process innovation adoption (Bunduchi & Smart, forthcoming) to the case of RFID technology. Data was collected by interviewing participants in the RFID adoption process in supply network settings, and by examining a range of publicly available information on RFID development. The data were used to test and expand the theoretical framework.

**Findings:** Of the six main categories of generic process innovation costs, four were identified as applicable in the case of RFID adoption by early adopters: development, switching, cost of capital and implementation. No evidence was found for initiation and relational costs. In addition, a seventh category of costs was identified as applicable to the adoption of RFID in supply networks: ethical costs associated with privacy and health issues.

**Research limitations:** Further empirical work is required to test the generalisability of the findings. Because RFID technology is still in the early phases of development, the research has been able to consider only early adopters: further work is required as the technology matures to assess the impact of costs throughout the technology development lifecycle.

**Practical implications:** The work demonstrates that when considering the adoption of RFID managers need to look at a range of potential costs in making the investment decision. Policy makers also need to consider how organizations consider a range of costs that may not be explicitly specified when making adoption decisions.

**Originality/value:** The paper tests and extends the generic framework of costs associated with process innovations in supply networks. The study also clarifies the various costs involved in the adoption of RFID technologies by early adopters, and their influence on the decision to adopt.

**Keywords:** RFID, Costs, Process innovation, Interorganizational

**Paper type:** Research paper

## INTRODUCTION

Operations improvement often depends on process innovations and, in particular, on technological innovations. To date studies of innovations have tended to concentrate on the adoption of innovations by individuals or single organizations. However, the drive for improved operations efficiency has led firms to take a broader perspective and to look to make improvements along supply chains. Consequently, process innovations increasingly happen, at least in part, at the interface of organizations. Radio frequency identification (RFID) is one such innovation. RFID is receiving increasing coverage in the operations management literature as a technology with a number of potential uses in tracking and tracing entities, including goods, equipment and people (Banks *et al.* 2007). In the setting of supply management it has been suggested that RFID will help organizations to make supply chains more efficient by ensuring that goods can be traced right through the chain. In 2003 Wal-Mart issued a mandate to its one hundred largest suppliers to start using RFID tags on pallets of goods sent to Wal-Mart no later than January 2005. Other organizations followed Wal-Mart in mandating the use of RFID. Although Wal-Mart has not been entirely successful in persuading all its suppliers to implement RFID, the high profile status of Wal-Mart and the widespread reporting of its initiative in the business media helped to raise awareness of RFID and contributed to the initiation of pilot studies of RFID use in retailing and beyond (Brown & Russell 2007). Nevertheless, despite the growing interest in RFID, the business case for RFID implementation in many settings has not yet been proven (Curtin *et al.* 2007; Loebbecke 2007; Wu *et al.* 2006).

Developing a business case requires a clear understanding of the potential uses of the technology under examination, and of the potential benefits and costs associated with its implementation. Curtin *et al.* (2007) describe the potential uses of RFID under four broad headings: business-to-business (B2B) logistics (see also Attaran 2007; Bottani & Rizzi 2008; Chow *et al.* 2007; Fosso Wamba *et al.* 2008; Karkkainen 2003; Loebbecke 2007), internal operations (see also Ngai *et al.* 2007a; Ngai *et al.* 2007b), business-to-consumer (B2C) marketing and sales, and B2B services. In addition, Lee *et al.* (2008) suggest applications in the B2C service sector. There is also a growing discussion of the benefits side of the cost-benefit equation in considering what RFID may offer (Bottani & Rizzi 2008; Fosso Wamba *et al.* 2008; Ngai *et al.* 2007a; Tzeng *et al.* 2008). Although costs have been alluded to (see for example Ngai & Gunasekaran 2009) there has been no systematic attempt to evaluate the full costs of implementation beyond the cost of RFID equipment. Nevertheless, the cost of RFID has been identified as one of the most significant limitations to its widespread adoption (Bottani & Rizzi 2008). In a comprehensive study of RFID applications in supply chains and beyond, Banks *et al.* (2007) found that several different factors, many of which could be considered under the heading of 'costs', were identified as barriers to the adoption of RFID. These factors included: equipment costs in the automotive industry (including software, hardware and, in particular, RFID tags); the requirement for process change in the automotive supply chain, animal tracking, warehouse and distribution centres; human factors such as resistance to change in RFID adoption for animal tracking; and the lack of commonly accepted technology interface standards in hospital settings. To understand the adoption of RFID technologies in supply networks it is therefore imperative to understand the various costs associated with this type of innovation and assess their influence on the pattern of innovation.

Recent work has developed a systematic framework for examining the costs associated with interorganizational process innovations (Bunduchi & Smart, forthcoming). This paper uses RFID as an

exemplar innovation to test and build upon that framework. In doing so, we clarify the different categories of costs associated with the adoption of RFID technologies in supply networks, and explain the role of these costs in shaping the pattern of RFID innovation. We contribute to the growing literature on RFID diffusion and provide a guide for managers in developing a robust business case for RFID adoption. The research described here adds to the current innovation and operations management literature by clarifying the components of the cost variable, one of the crucial factors shaping the adoption of process innovations in supply network settings.

To achieve these aims, our research draws on data obtained from interviews with representatives from a range of stakeholders, including equipment suppliers, standards development bodies and consultants involved in RFID use in supply networks, to show that the costs of implementation are not confined to the purchase of hardware and software. We seek to address two research questions:

1. Which of the generic interorganizational process innovation costs identified by Bunduchi and Smart's (forthcoming) generic framework apply to the adoption of RFID applications in supply networks?
2. What, if any, are the influences of these different costs on the adoption of RFID within supply network settings?

## LITERATURE REVIEW

### Process Innovation Adoption

Commentators on earlier versions of this paper<sup>1</sup> questioned whether cost is important in assessing innovation adoption. While it may be true that for the adoption of product innovations by individuals, factors such as social cachet can play an important role in determining the likelihood adoption, process innovations in operations settings are aimed at reducing costs or increasing revenues within organizations (Garcia & Calantone 2002); the success of this desire for improved financial returns will depend on the cost of the technology. Consequently, the costs organizations incur during the adoption of process innovations in general, and interorganizational process innovations in particular, play a significant role in the likelihood of adoption. Research in information technology (IT) innovation has studied the adoption of IT interorganizational process innovations such as electronic data interchange and, more recently, Internet-based interorganizational systems, and has identified the costs associated with their adoption as one of the significant drivers of (or obstacles to) adoption (Chwelos *et al.* 2001; Premkumar *et al.* 1994; Zhu *et al.* 2006). A comprehensive review of the literature (Bunduchi & Smart forthcoming) identified six categories of tangible and intangible costs associated with interorganizational process innovation that reflect the stage of organizational innovation. The review argues that the six categories of costs influence the pattern of process innovation in supply networks.

### *Context: RFID as a Technology Innovation in Supply Networks*

In outlining a research agenda for RFID, Curtin *et al.* (2007) suggest the need to examine the 'adoption dimension', during which RFID is developed, accepted and implemented by organizations. One of the

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<sup>1</sup> An earlier version of this paper was presented at the Academy of Management, Philadelphia, 2007.

main contexts in which RFID is adopted for track and trace items is supply networks. Supply networks have been defined as “*interconnected entities whose primary purpose is the procurement, use and transformation of resources to provide packages of goods and services*” (Harland *et al.* 2001: 22). They involve the bringing together of organizations and the resources that support those organizations, including IT. The adoption of a process innovation within a network can be influenced by, and itself influence, the transfer and distribution of information by other organizations within that network. The associated innovation costs can therefore also be influenced by the network context.

RFID is an automatic identification technology based on radio frequency (RF), which enables the collection of data using radio signals. We focus here on the supply network settings in which RFID is seen as a replacement for, or complement to, barcodes (Wu *et al.* 2006). Within a supply network context, RFID systems comprise three main components: a tag on which data is stored, a reader incorporating an antenna and a decoder, and a computer application which processes the data from the tag. Although similar in their use, barcode and RFID are fundamentally different technologies. Barcodes rely on optical technology to capture encoded data; RFID uses RF technologies. The use of RF has enabled new functionality beyond that offered by barcodes: for example it eliminates the need for the line of sight in reading item information, it can enable item data to be updated, and it makes possible selective and simultaneous reading without human intervention (Garfinkel & Holtzman 2006). Because of these significant improvements, it has been argued that RFID will reduce costs through automation and increase the visibility of goods throughout the entire supply network (Jones *et al.* 2005).

The pace of RFID deployment has increased significantly since 2000 (Leaver 2004) driven by the mandates of powerful retailers such as Wal-Mart, Metro and Tesco, and of governmental agencies such as the US Department of Defence (Brown & Russell 2007; Gerst & Bunduchi 2005a). More recently, several RFID supply chain applications have been identified outside the retail industry, ranging from the global automotive industry, through animal tracking in Texas, to hospital applications for tracking patients and drugs (Banks *et al.* 2007). However, despite the claimed advantages of RFID over barcode, the latter remains the dominant technology for item tracking and tracing, with researchers questioning whether there is yet a clear business case for RFID adoption (Jones *et al.* 2005; Wu *et al.* 2006). As indicated earlier, the high costs associated with RFID can be seen to be a significant obstacle to the full deployment of RFID, at least for applications in the context of supply networks where barcode provides a viable alternative (Banks *et al.* 2007).

### ***Interorganizational Innovation Adoption Costs in Supply Networks***

To identify the costs associated with RFID adoption in supply networks, our research draws from the framework of innovation costs developed by Bunduchi and Smart (forthcoming). The framework maps the different costs associated with the adoption of process innovations in supply networks onto the generic stages of organizational innovation developed by Thompson (1965): (i) the *generation* of an innovative idea or proposal; (ii) the *acceptance* of that innovation, represented by an organizational mandate for change; and (iii) the *implementation* of the innovation so that it becomes ingrained within the routines of the organization. In the context of RFID adoption, Curtin *et al.* (2007) outlined an RFID “adoption dimension”, including development, adoption and implementation, which can readily be mapped onto the three organizational innovation stages outlined by Thompson. The different categories

of innovation costs identified by Bunduchi and Smart (forthcoming) are summarised in Table 1 and their association with the specific innovation stages is outlined in this section.

*Table 1. Categories of inter-organizational process innovation adoption costs in supply networks (from Authors, forthcoming)*

Stage	Types of Cost	Examples
GENERATION	DEVELOPMENT COSTS (for developers): costs associated with participation in the elaboration of a new technology	<p><b>Internal costs:</b> internal research and development costs involved in in-house development.</p> <p><b>External costs:</b> participation and negotiation costs associated with the involvement in collaborative arrangements.</p>
	INITIATION COSTS (for acquirers): costs associated with building awareness about a new innovation	<b>Awareness buildings costs</b>
ACCEPTANCE	SWITCHING COSTS: compatibility costs arising from the need for compatibility with existing assets when changing from an existing technology to a new technology	<p><b>Technological compatibility costs:</b> complementary technological resources, e.g. costs associated with incumbent software and hardware.</p> <p><b>Organizational compatibility costs:</b> complementary organizational resources, e.g. changing the existing capabilities in marketing, service or distribution.</p>
	COST OF CAPITAL: costs associated with the uncertainty of investment in innovation	<p>Costs associated with <b>technology uncertainties</b></p> <ul style="list-style-type: none"> <li>• <i>Financial risk:</i> the costs incurred fail to deliver the projected benefits either because benefits were overestimated and/or costs were underestimated.</li> <li>• <i>Technical risk:</i> the delivered technical performance is below what was anticipated, and results from a technology being immature, poorly understood, unreliable, obsolete or unstable.</li> <li>• <i>Project risk:</i> ineffective and/or inefficient project delivery resulting from lack of appropriate skills and expertise to deal with the technological complexity, longer than anticipated implementation time, and/or a high turnover of key personnel.</li> <li>• <i>Political risk:</i> situations in which a technology adoption project and/or the technology itself is subjected to organizational political infighting or resistance.</li> <li>• <i>Security risk:</i> the inability of an organization and its exchange parties to trust the information technology environment. Includes contingency risk associated with accidents, disasters and viruses; the risk of non-use, under-use or misuse of the technology by the intended users; abuse of the system by users within the adopting organization, including the potential for sabotage and malicious destruction; and the possibility of destruction of, or damage to, the system by those outside the organization.</li> <li>• <i>Incompatibility risk:</i> the developed technology is incompatible with existing hardware and software and with user wants. It results from poor understanding of the project brief or client needs, and fundamental changes in the adoption environment that render the functionalities embodied in the technology obsolete or</li> </ul>

		inappropriate on completion of the project.
		<p>Costs associated with <b>market uncertainties</b></p> <ul style="list-style-type: none"> <li>• <i>Competitive risks</i>: negative reactions by customers, competitors and/or technology suppliers.</li> <li>• <i>Reputational risks</i>: potential negative reactions by the general public, the media, government or other potential stakeholders.</li> </ul>
IMPLEMENTATION	IMPLEMENTATION COSTS: the costs associated with acquiring and implementing an interorganizational process innovation	<p><b>Direct technology costs</b></p> <ul style="list-style-type: none"> <li>• <i>Initial user specification of the system</i> including initial hardware, software and installation costs; and installation and configuration costs, which include consultancy support, installation engineers and networking hardware and software</li> <li>• <i>Unexpected hardware and software costs</i> including increased processor power and software upgrades</li> <li>• <i>Other sources of direct costs</i> including security costs to ensure protection against viruses and abuse of the technology; system development costs, including the time spent customising a system; environmental operating costs to include, for example, the power required to run the system; and maintenance costs such as yearly service contracts</li> </ul>
	RELATIONAL COSTS: costs associated with the relational context in which the innovation is implemented	<p><b>Indirect social costs</b></p> <ul style="list-style-type: none"> <li>• <i>Organizational costs</i>: losses in organizational productivity; strains on organizational resources; business process reengineering; organizational restructuring</li> <li>• <i>Human costs</i>: the time and resources expended by managers and operators in getting the system to work; systems support activities; training costs; changes in salaries (such as pay increases based on improved employee flexibility); and the resources required to deal with the consequences of staff turnover</li> </ul>
		Cost associated with <b>lack of trust</b> between supply network partners leading to ill feelings, resentment, tension, conflicts and withdrawal between innovation adopters.

Each of the costs manifests mainly in one of the three stages, but is not exclusive to that stage. For example, the cost of capital emerges during the acceptance stage, when the organization is looking for capital to invest in the new technology, but it can extend well into the implementation stage. Similarly, the development costs associated with the involvement in technology development consortia emerge during the generation stage, but may continue into subsequent stages as technology standardisation efforts may be prolonged.

### ***Generation***

The process of innovation adoption starts with the initiation of an idea or proposal that, when fully implemented, will result in some change within the adopting organization (Thompson 1965). There are two types of organizational innovators: those that generate the innovation themselves (developers) and those that acquire the innovation from others (acquirers) (Bunduchi & Smart forthcoming; Damanpour & Wischnevsky 2006; Gopalkrishnan & Damanpour 1997). At the generation stage, two types of cost dominate: development costs, largely incurred by developers, and initiation costs, largely incurred by acquirers.

#### ***Development costs***

Development may take place either in-house (internal development costs) or through collaboration with others (external development costs). Internal development costs include the costs associated with research and development activities. External development costs include the different resources that are necessary to participate in standard setting consortia (Antonelli 1994), including the time and the human resources involved in collaborative development (Foray 1994) and delays due to the negotiations required to overcome incompatibilities between the positions of different stakeholders (Farrell & Saloner 1988).

#### ***Initiation costs***

The acquisition of innovations from others involves a range of activities, including learning about the innovation and assessing the suitability of that innovation for the needs of the organization (Damanpour & Wischnevsky 2006; Meyer & Goes 1988). This process of hunting for and evaluating alternative innovations requires organizations to commit resources to identifying the vendors and the products available, and to consider how those products can be used effectively in the organization.

### ***Acceptance***

During the acceptance stage, an organization decides to adopt an innovation, and appropriate mandate and resources are provided to support the change. In this phase other costs, in particular switching costs and the cost of capital, come to the fore.

#### ***Switching costs***

Introducing any process innovation generally involves a range of assets, which may be specific to that particular application and which would have little value for other applications (Farrell & Saloner 1985; Farrell & Shapiro 1988; Shapiro & Varian 1999; Tang & Zannetos 1992). Replacing an existing interorganizational technology with a new technology often means losing the investment in these specific assets, resulting in switching costs (Zhu *et al.* 2006). These kinds of switching costs, which arise from incompatible technologies, are referred to as compatibility costs (Klemperer 1995) and arise as a consequence of two complementary resource types: technological and organizational (Powell & Dent-Micallef 1997).

#### ***Cost of capital***

The capital investment associated with the adoption of any innovation can be in the form of debt, equity or retained earnings. The cost of capital depends on the risks associated with that particular investment, and the degree of risk depends on the level of uncertainty associated with the technology investment (Markus 2000; Mata *et al.* 1995). Two major sources of risks in IT investments can be applied to process innovations: (i) technological uncertainty, which reflects the risk that the investment



may not reach its performance targets within a reasonable timeframe; and (ii) market uncertainty, which reflects the risks that users will not accept new products or services associated with the investment (Mata *et al.* 1995).

### ***Implementation***

During implementation a technology is installed and appropriate organizational routines are established within the organization (Thompson 1965).

#### ***Implementation costs***

Two types of costs are associated with the implementation of a process innovation (Hochstrasser 1992): (i) direct costs that can be attributed to the implementation and operation of a particular technology (Irani *et al.* 1997; Irani & Love 2000/2001); and (ii) indirect costs, which include the organizational and human factors associated with the introduction of a new technology (Irani *et al.* 1997; Irani & Love 2000/2001; Ryan & Harrison 2000).

#### ***Relational costs***

When technologies are implemented to support exchanges between supply network actors, the nature of these relationships, in particular the existence of trust between the partners, influences the costs involved in adoption (Johnston & Vitale 1988). The absence of trust influences the adoption of an interorganizational innovation either directly, through obstructing the adoption of the innovation by the users (Allen *et al.* 2000; Gerst & Bunduchi 2005b; Hart & Saunders 1998; Meier 1995), or indirectly through increasing the transaction costs involved in switching to a new technology system (Bromiley & Cummings 1995; Chiles & McMackin 1996; Dyer & Chu 2003; Smith Ring & Van de Ven 1992).

Thus, Bunduchi and Smart's (forthcoming) framework identifies six categories of costs. Although the framework associates costs with a particular stage in the innovation process, it does not claim that the particular types of cost are associated exclusively with that stage. Rather Bunduchi and Smart (suggest that the costs will predominantly be incurred in a particular stage, but that there may be an element of some of the costs in the earlier or, particularly, later stages. Development and initiation costs are dominant during the generation phase; switching costs and the costs of capital become important during the acceptance phase; and implementation and relational costs come to the fore at the implementation stage. The framework is tested using data from early adopters of RFID in supply networks.

## **METHODOLOGY**

The exploratory nature of the study meant it was appropriate to use a qualitative approach. A qualitative study is particularly suited to helping to answer 'how' and 'why' questions (Yin 2003). In this study the aim was to explore *how* innovation costs are influencing the organizational adoption of RFID and *why* these influences exist, rather than to quantify the precise measure of these influences. Qualitative studies are also suited to situations in which the area being studied is still evolving and when researchers are unable to control the events that are being studied (Yin 2003), both of which apply in studying the development of RFID – still an emergent technology - within supply networks.

Data was gathered from primary and secondary sources. The secondary sources comprised publicly available documentation on RFID development, articles from practitioner magazines and the websites of organizations involved in RFID development and implementation. The secondary data was augmented by ten in-depth semi-structured interviews with people active in RFID adoption. Interviewees were identified using opportunistic sampling (Miles & Huberman 1994). All the

interviewees were senior managers or experienced RFID consultants involved in the adoption of RFID technologies, including representatives of international standards development bodies, global technology developers and vendors, and major organizations using RFID, who were selected for their capability to act as key informants (Patton 1980).

*Table 2: List of interviewees*

<b>Interviewee</b>	<b>Role</b>	<b>Code</b>
A representative serving on the ISO RFID committee	Managing director of a technology consultancy company /chair of the RFID and barcode working groups of a national standards consortium / ISO technical committee member	ISO
Two representatives of the EPC Global process, one from the United States and one from the UK	EPCglobal User Group chair / a Product Manager for EPCglobal US	EPCA
	An EPCglobal RFID Adoption Programme Manager	EPCUK
A representative from the Auto-ID Centre that spawned the EPC initiative	Technical director of one of the Auto-ID centres	AID
Two RFID user representatives, one from a car manufacturer, and one from a supplier of RFID components that also uses RFID within some of its own supply chain applications	Information Technology Manager	CM
	Innovation Manager	CS
Two representatives of technology vendors	Director of Business Development for RFID & supply chain	SV1
	Global account manager for an RFID component supplier client	SV2
Two representatives from two consultancies that provide RFID services	Consultant	C1
	Consultant	C2

A description of the interviewees is provided in Table 2. Respondent validation was used to check the accuracy of the data obtained during the interviews (Payne 1999). Interviews were carried out using an interview guide (Patton 1980), and focused on interviewees' experiences of RFID implementation and technology development while allowing the interviewers to develop further questions as specific issues emerged.

Transcripts were analysed using template analysis (also known as 'thematic coding') (King 1998). Template analysis was chosen because it allowed us to develop an initial set of codes based on the framework of innovation costs (Bunduchi & Smart, forthcoming) that guided our research, to test the initial set of codes in the template on early interviews and to refine the codes as the analysis progressed. The initial list of costs included six broad categories, with subcategories for the different components of costs. This list was revised iteratively during the analysis process as some codes were

seen as irrelevant or proved to be too narrow (Miles & Huberman 1994): for example, the different categories of risks associated with technological and market uncertainty costs were originally included in the list of costs developed based on the generic framework, but as the data analysis proceeded it became evident that such subcategories were not supported by the data. Consequently they were replaced with two generic categories: technology and market risks. Other costs were added as new categories were identified during the analysis (for example, the initial framework did not identify potential ethical costs, which emerged as relevant during the research). Template analysis has the advantage of being sufficiently flexible to enable the addition of codes to account for these emergent costs. The approach suited our aim not only to test, but also to improve, the theoretical framework that guided the research. Being able to modify the categories of costs within the framework was essential to enable us to develop the framework to reflect the realities of RFID adoption costs in supply networks.

Each transcript was coded by one researcher according to the costs detailed in the initial typology and other potential costs were assigned codes as they emerged from the interview data. The coding was checked by a second author and the authors met to agree on coding. Where agreement could not be reached the coded fragment was excluded from the analysis. Further analysis of the case materials was based on making detailed descriptions of the materials and of the setting (Stake 1995). The data were analysed by making comparisons, noting relationships between variables, and identifying patterns and themes (Miles & Huberman 1994) from which the researchers built a logical chain of evidence.

## RESULTS AND DISCUSSION

The research concentrated on early adopters of the technology, who were largely focussed on the generation and acceptance stages, although some issues in implementation were also identified by interviewees. In this study few applications had moved beyond the pilot stage. This early stage of development is characteristic of the current state of RFID applications and can be seen in the review of RFID applications by Banks et al. (2007), in which most of the exemplar application cases were pilot implementations by early adopters.

### *Development Costs*

The generation stage concentrates on developing systems that enable innovations to be used within a particular setting. With innovations such as RFID, that are specifically being considered for use in network settings, the development of standards is an important part of the adoption process. RFID technology standards development activities were concentrated in two central organizations: the International Standards Organization (ISO) and Electronic Product Code Global (EPCglobal). ISO focused its efforts on developing high level RFID standards; its activities were largely driven by the interests of the manufacturers of RFID hardware. In contrast, EPCglobal focused on data specific standards and applications, and its work was driven by IT vendors, large retailers and their large suppliers. Both the ISO and EPC fora were characterised by limited end-user participation and support, with only larger organizations funding the standardisation costs (with ISO activity principally funded by RFID components manufacturers, and retailers, including Wal-Mart and Tesco, and their large suppliers such as Proctor and Gamble and Nestlé funding EPCGlobal activities). This became clear when involvement in development activity was discussed with an EPC representative: *“Wal-Mart is very actively involved... Their mandate [...] created the fire and the urgency around the development of standards. They were the first to put a line in the sand when they said that their one hundred largest suppliers must be shifting goods [with RFID tags] by January 1 2005 to their distribution centres in Texas. Metro also had a mandate. Tesco had a bit of a mandate, and Target and Albertsons in the US*

*also had a mandate. ....The US Department of Defence, which is bigger than all of those combined, also mandated the use of RFID and EPC. So you could say it was those six mandates that were a big driver for the community, and they have all been actively involved” (EPCA).*

The larger early adopters were often involved in both ISO and EPCglobal standardisation activities in order to gain the full benefits from influencing the shaping of technology development. The Innovation Manager of an RFID components manufacturer explained that “[*Company*] is working actively in both, EPC global and ISO organisations. Our business strategy is guiding the involvement in standardisation bodies. For each of the distinct areas of application in which we manufacture [RFID components], we are working either in both or at least in one of [...] the different standardisation committees. The business pressure gives us a strong standardisation focus because it is much more costly to produce ten different [RFID components] than only one. Additionally, if one standard is available, higher volumes of an [RFID component] can be produced. Nevertheless, in some areas, we have to show some flexibility. That consequently drives cost” (CS). The bigger adopters therefore incurred external development costs for RFID, including the fees paid to be represented in one or both standardisation committees, and the time and effort spent in drafting the specifications. Generally, the level of an organization’s expenditure on the standardisation process has been related to its ability to push the development of the technology to reflect its own requirements. According to the representative of EPCGlobal US: “*Some of the sponsors would pay their dues and would just show up to the meetings three times a year, some of them would be on the phone every week and come in to visit saying, ‘lets help with this’ and ‘we’ll help you write the draft of that’” (AID).*

A readily identifiable group of users initiated the development of RFID, with smaller users simply acting as mandated followers and trying to minimise their own costs. The interviewees agreed that the strategy for the majority of those adopting RFID in supply network settings would be for them to acquire the technology from an external vendor. There was no evidence of the majority of users, and in particular smaller users, being involved in developing RFID standardisation. For example, one of our respondents was a car manufacturer actively involved in piloting RFID technology at one site. Their IT Manager commented: “*for [Car Company] the important point is that the technology fits our needs and works properly. Therefore, we are not involved in any standardisation activity. But we have an eye on the technology market and are very well aware of any kind of monopolistic behaviour that is normally translated directly into price. Often, once a standard product is developed, the vendor aims for unreasonably high prices” (CM).* However, even where they were not involved in standardisation activities, the companies we talked with were acting as “lead users” (von Hippel 1986) and were involved in developing the technology alongside the vendors. According to the same interviewee, “*We were literally forced to develop the technology further, together with the technology vendor, to use it. First of all, the coverage of approximately one metre was too short for our purposes. By chance, we discovered that an additional ferrite plate integrated into the transponder increased the coverage to three metres. For a long time, a second weakness was the antenna; it often breaks down without any reason. Unfortunately, the transponders are heat-resistant only up to sixty degrees centigrade. This is important if a (car) body has to go through varnishing. Another big issue was then development of a fastener for the transponder. The vendor only made available the transponder itself. But the transponder has to be fixed to the body somewhere, without damaging it. This problem was solved with by developing a plastic holder which could be attached without damaging the body and could be read by the dispatch points” (CM).* These lead users, together with the vendors, were involved in shaping the technology in the early stages of its evolution. They were consequently incurring the costs

associated with experimenting and working with the technology vendors to develop and refine solutions.

### ***Initiation Costs***

In the interviews we found no strong evidence of initiation costs. The interviewees referred to activities involved in “*keeping an eye on the technology market*” (see the quotation by the car manufacturer representative, CM, above), but the focus was almost exclusively on developing the technology either through participation in standardisation committees or through working closely with a technology vendor. The limited emphasis placed on activities associated with gaining awareness of a technology and technological solutions which characterises acquirers may reflect the fact that the interviewees were all involved in the early stage development of RFID, or were lead users or early adopter organizations. At this stage of innovation evolution, the absence of a dominant design meant that the chance to acquire fully developed and readily implemented technology solutions was not available (Utterback & Abernathy, 1975). Instead, users were “*forced to develop the technology with the vendor*” (see CM quote above). Therefore, the RFID users we interviewed at this very early stage of RFID development could be characterised as developers rather than acquirers of innovation. This would account for the fact that we did not find evidence of initiation costs.

The majority of potential RFID users are not yet involved in RFID adoption, and may not be for some time. When they become involved, during the later stages of innovation diffusion as majority users and laggards (Rogers 2003), they will face higher initiation costs, rather than development costs. The development costs are largely being borne by the lead users and early adopters.

### ***Switching Costs***

In their framework of costs, Bunduchi and Smart (forthcoming) differentiate between organizational compatibility costs and technological compatibility costs. While this differentiation was also evident in our interviews, a distinction between what we call future (or forward) and context (or backward) compatibility costs was raised more frequently. Future/forward compatibility costs refer to the costs related to potential compatibility problems between the current RFID applications and any future “standard” solution. Context/backward compatibility costs include the cost of integrating RFID applications with existing technologies within the adoption context. The first cost is linked to the RFID standardisation process. Interviewees agreed that one of the major concerns of users about the adoption of RFID adoption was the need for common, global standards. “*The important thing ... is that when a manufacturer sticks a tag on his product, he doesn’t know where that’s going to end up. It could be in any country, it could potentially be in any supply chain in any industry sector. It’s very important ... that tag will be readable wherever it goes, otherwise he has to have different SKUs for different places... that causes a huge amount of cost ..... So it’s very important that we end up with one tag that works across the world and in every sector*” (EPCUK). At the time of writing, the RFID standardisation landscape was complex, with a number of overlapping standards. For example there were both ISO and EPCglobal air interface standards. In addition, a number of areas did not have well defined, generic standards. The lack of widely accepted generic RFID standards was identified by the users we interviewed as a critical variable affecting their decision on whether to move from a pilot study to full, company-wide implementation. As one of the consultants explained: “*Users are*

*extremely sensitive about standardisation ... standards can be a danger, because everyone waits for everyone else and does not do anything” (C2).* Many of the benefits of RFID come from tracking items as they move between companies and countries. The benefits of RFID are likely to be lost if multinational enterprises are forced to make investments in different RFID technologies for operations in different areas. The wide-spread adoption of RFID technologies was thus being slowed by the fear that users would be locked in to a standard that would subsequently be abandoned, and that technology vendors would not adhere to global standards.

In addition to concerns about potential compatibility problems between extant RFID systems and any future RFID solution (forward compatibility), a second physical switching cost was identified. This related to the compatibility between RFID technologies and existing technologies within the adoption context (here backward compatibility); integration of RFID applications with existing processes was seen as adding significant compatibility costs: *“Normally, the company that delivers an application also delivers other equipment. This is not the case with RFID. ...Currently, the RFID applications are too different. So a system integrator is needed to integrate the different environment” (C2).* However, the interviewees were much less concerned with backward compatibility than with potential forward compatibility. The lack of common global standards resulted in the market for RFID hardware and software being characterised by a large number of vendors offering diverse RFID solutions. This proliferation of vendors and solutions increased users’ concerns over future compatibility.

### ***Cost of Capital***

#### *Technology uncertainty costs*

Due to the pressures for low costs tagging, the implementation of RFID within supply network settings posed a number of problems. These included the limited availability of computational power to process data, the fact that the information read from the tag may be unreliable and the fact that some tags were not read due to signals from tags conflicting at the time of the reading. Wu et al. (2006) have argued that adoption of a new technology can happen on a large scale only when a technology is 100% reliable. Our data confirms this finding. Those who had carried out pilot studies with RFID described an immature technology, where users and technology vendors had to work together to develop solutions. The difficulties outlined by the car manufacturer (CM) epitomised the problems faced by adopters (see the discussion in the section on Development Costs). A second user (CS) encountered major problems with data accuracy because tags were being misread. The user experienced significant difficulties attaching RFID tags to a range of different packaging surfaces, meaning that readers were unable to read tags with any degree of reliability, resulting in incomplete logistics data. In addition, the software supporting the RFID system, which was meant to facilitate data processing, did not integrate well with other applications and set-up took much more time and effort than was originally envisaged: *“In this project, we had several trials. There were some issues. First of all, the accuracy of data. Next, the software, which did not work adequately and could not be integrated sufficiently with back-end systems. Another issue was the definite identification of the tag. On some of the materials used, like wooden pallets, identification proved difficult and the labels did not stick very well. This can lead to a loss of information if they come off. Therefore, it could be that the correct data is not available, and that the flow of logistic data is not reliable.” (CS)*

All interviewees agreed that the costs associated with the uncertainty in RFID technology development were high. However, initial investments in pilot studies could, even with uncertainty surrounding the technology, reduce subsequent training costs through the acquisition of firsthand knowledge of the use

of RFID: *“My key message to all companies is, start experimenting because ..., it’s not something you can implement and will always work in your situation. So start learning because if you don’t start investing, your competitors will and you’ll be behind.”* (SV2).

#### *Market uncertainty costs*

In the case of RFID, the major source of market uncertainty costs appeared to be the highly fragmented nature of the RFID vendor landscape. In an attempt to gain an advantage over competitors, the larger RFID vendors were announcing many new products. However, the vendors had not released generally available solutions and were struggling to keep up with increasing user demands. As one interviewee explained: *“The situation is characterised by a very split market, many vendors on the hard- and software side, and few technology standards which will see the light very slowly”* (C1). Potential RFID customers were under significant cost pressures and were looking for “easy to implement” and “easy to understand” solutions that had been thoroughly tested and proven in the market. There was no equivalent of Microsoft Windows with which vendors of other complementary products could seek to comply. *“RFID still demonstrates the characteristics of a pilot and has weaknesses such as the business case (ROI) and ... standardisation issues in terms of different interface protocols, performance and data structure”* (CS). The lack of anything that even vaguely promised to develop into a “killer application” had increased the levels of apprehension among potential users about investing in RFID, reducing the likelihood of RFID adoption: *“the user commitment will only come when real proof of benefit, a real business case, can be shown”* (C1). These high levels of customer (user) uncertainty added to the market uncertainty costs.

#### **Implementation Costs**

Implementation costs include direct and indirect costs. Direct costs are linked to the technology itself while indirect costs include the organizational and social costs associated with the investment.

#### *Direct costs*

Generally, the interviewees divided the direct implementation costs into two major categories: up-front investment costs, such as the investments in readers and initial hardware and software costs, and the ongoing costs associated with tags. These costs occur at different times in the innovation cycle depending on position in the supply network: *“the retailer has the problem of up-front investment but then gets benefit. [...] The manufacturer has the opposite problem of not so much up-front investment but ongoing costs”* (EPCUK). There could also be different cost distribution depending on how RFID was implemented. Users could either invest in what it is termed “slap and ship”, where the tags are attached to items but the users make no investment in systems to manage the data, or redesign their supply processes to derive the full benefits from the functionality associated with RFID. *“What [users] are really thinking of and trying to work out .... is how can we change our operations so that we can get some benefit from the use of RFID? ... If you’re just sticking a label on at the end that’s just cost, you gain virtually nothing”* (EPCUK).

At the time of the study, low cost passive RFID tags cost somewhere between \$0.18 and \$0.40 (Schuman 2006) and were therefore still too expensive for many applications. The cost of tags was seen as a big reason for the widespread delays in adoption of RFID technologies on a large scale. Whereas \$0.18 may justify case-level tagging, the introduction of item-level tagging for low value items was seen as unrealistic by all the respondents. *“...even one cent on a tin of beans is expensive.*

*The cost of putting RFID tags on a consumer unit level, even assuming five cents, is almost the same as the gross profit of Tesco” (ISO).*

In addition to the cost of tags, the interviewees identified other direct implementation costs, including the cost of (i) readers at every identification point; (ii) software development and implementation; (iii) integration with the existing systems; and (iv) supporting infrastructure. For example, one respondent explained: *“retailers have a big investment in readers; they probably will need readers at every store...some thousands of readers that are going to need to be put in place, at distribution centres”* (EPCUK). The cost of implementation is directly related to the scale of implementation. This partially explains why most RFID projects were being carried out only as pilots.

One issue in the implementation of RFID was the volume of data gathered from tags, particularly as many organizations are currently running two track and trace systems in parallel and trying to reconcile the data: *“There are lots of data in the reporting system...RFID data are not stored in production systems to avoid disturbing the operations”* (SV1). There were high costs associated with the storage and processing of these data. The data processing costs had not been analysed and factored into investments by many who were considering implementation.

#### *Indirect costs*

The implementation of RFID was seen by all the respondents as a significant opportunity to redesign business processes and change the organisation: *“don’t think RFID is a replacement of a barcode, but it will enable us to fundamentally change some business processes, and that is where the real benefit will come from. If you just consider RFID as a replacement of barcode, the return on investment will be minimal. But if you can actually fundamentally change business processes, do things smarter and do things different, that is where real benefits will come from.”* (SV2). The respondents were well aware of potential organizational and human costs associated with RFID adoption. For example, when asked about the major costs associated with the adoption of RFID, one consultant talked of: *“change of processes, training, change management, IT system integration, interfaces, operation, ... assistance during conception and realization phase”* (C2). Organizational costs associated with change management and business process re-engineering, and human costs associated with training and employees time were acknowledged as significant. In particular, the costs of business process redesign were seen as a priority. Training costs were also perceived as being high because of the shortage of trainers with the necessary skills and the consequent need for users to teach themselves. An added problem with the training costs was the global nature of the supply chains; to gain the full benefits claimed for RFID, systems needed to be implemented on a global scale to achieve network economies. This was difficult because implementation required experts trained in RFID technologies, and such experts were scarce: *“One of the problems ... with RFID is that it’ll have to be put in fairly quickly, ... tens of thousands of devices, and the skills to do that don’t exist”* (ISO). Consequently, in the early stages of RFID adoption, when the technology was new and the design of the business processes required to support RFID application was unstable, implementation costs were particularly high and deterred widespread adoption of RFID in supply networks.

#### **Relational Costs**

##### *Trust*



If RFID is to achieve its aim of enhancing the visibility of goods throughout the supply network the technology has to be implemented across company boundaries. To unlock the potential of RFID beyond the boundaries of an organization, supply network partners need to work together to allow each other to access the data generated by the use of RFID.

Our study found mixed evidence about the level of trust and collaboration between supply network partners. On the one hand, the technology was being developed collaboratively, often within standards setting consortia in which large retailers and their large suppliers participated together, notably in EPCglobal. On the other hand, it was the large retailers and major suppliers that were driving the development and implementation of RFID; there was no evidence of a quest for collaboration between the large organizations and their smaller suppliers, who were largely absent from the development process (see the discussion in the Development Costs section). Moreover, some of the strongest supporters of RFID technologies were the companies whose mandates forced suppliers to introduce tags on their products in situations where the distribution of benefits arising from RFID adoption between the mandating organizations and their suppliers was unequal. Simple tagging (“slap and ship”) – which is what most suppliers did in order to meet the basic requirements of the mandates - does not offer any real benefit to suppliers. Indeed, suppliers saw their direct costs increase because RFID tags cost significantly more than barcode labels. All the benefits accrued to the retailers, who invested in RFID systems to gather and analyze the information provided from the tags in an effort to increase the efficiency of their logistics and supply chain operations. Most suppliers, and in particular small- and medium-sized suppliers, did not have the resources to fully implement an RFID system to deliver the same benefits experienced by larger organizations. The asymmetric distribution of costs and benefits across the supply network meant that suppliers had little incentive to adopt RFID. This partially explains why large retailers, such as Wal-Mart and Tesco, used coercive power – through a mandate for RFID adoption – to try to force their suppliers to adopt the technology, and also why suppliers were reluctant to invest in RFID. “[The] *challenges for individual companies [suppliers] are customer requirements that each and every palette has to have a tag on it. If not they are not their supplier any more. The [suppliers] companies... have real difficulties and are forced to implement a very short-term RFID solution without looking at benefits for their own company*” (C1). The approach of large retailers in trying to force adoption despite the lack of any obvious benefits for suppliers seems likely to have reduced trust between suppliers and the major retailers, and ran the risk that suppliers would become increasingly reluctant to invest in RFID applications that delivered no discernible benefits to them.

However, most RFID pilot projects were being carried out within the boundaries of a single organization. Because most respondents were involved only in these single organization studies they could not comment on the role of trust between a company and its suppliers in adoption success.

### ***Ethical Costs***

One set of costs which is generally ignored in the technology adoption literature, but which became apparent during our research, is ‘ethical’ costs. In the case of RFID, ethical costs include concerns about both privacy and health.

#### *Privacy concerns*

The costs associated with potential privacy concerns were mentioned as a significant threat for the deployment of RFID technologies at the interface with the end customers. “*Our main concern is that*

*consumers are not well enough educated about exactly what RFID is, how it works, what it can do, what it can't do. Benetton had to cancel their pilot because they put RFID tags in clothing and consumers actually had the idea that, like a big brother community, everybody was able to track and trace them through the city and know exactly where they were* (SV2). The Benetton case was not the only example of an organization having to rethink its tagging policy. Since 2000, a number of companies, including Wal-Mart and Gillette, have announced their intention to use item level tagging. Both Wal-Mart and Gillette abandoned these initiatives as a consequence of lobbying from consumer protections groups such as CASPIAN (Barut *et al.* 2006; McGinity 2004). Privacy groups argued that tagging consumer products gave retailers access to more information about individual consumer behaviour than could be obtained from store cards. In many cases, unlike with store card, consumer groups claimed that RFID data was obtained without the consent, real or implied, of customers (Barut *et al.* 2006; Jones *et al.* 2004; Peslak 2005).

Privacy concerns arise from the fact that RFID technology enables non-contact, non-line of sight communication, making it much more difficult for the possessor of an RFID tag to physically prevent unwanted or unauthorized communication with the tag. As one of the interviewees explained: *"Marks [& Spencer] are going to allow the customer to decide whether the tag that's put on your clothes will be killed when you buy it, because people believe that these tags can be read from a satellite. The reality is they can be read from about a metre, two metres at the most, but people are terrified..... an awful lot of women are scared that their dress size will be visible, particularly in America. They're scared they will be violated"* (ISO). Other forms of tags, such as magnetic strips, assume that the owner of the card is responsible for handing out the card to be read, making it possible for them to govern access to the information on the card. RFID tags render such a physical authorization irrelevant; any reader within the tag reading range can, theoretically, access the tag. However, there are limits to the range from which RFID tags can be read, particularly in the case of passive RFID tags used for item level tags reaching end customers. Moreover, as the Marks and Spencer example demonstrates, RFID tags can be destroyed once an item is purchased: *"... (the) kill functionality ... can render the tag dead, so it won't be useful once you perhaps take it from the store"* (EPCA).

While privacy concerns proved costly for the retailers that had to abandon part of their pilot RFID implementation, they appear much less of an issue further upstream in the supply chain: *"In the industrial area of logistics, it is no topic at all. Palette tags do not consist of personal data"* (C1). Moreover, in many cases, privacy costs are unlikely to accrue as projects are internal to one company and on a small scale.

This growing concern about the impact of technological innovation on privacy is nothing new. There are many examples of the costs of implementation being affected by the need to allay public concerns. For example, the provision of electronic patient records (EPR) in health services has raised concerns about how vulnerable the data will be to unauthorised access (Carney 2001; van der Ploeg *et al.* 2006). Organizations have to be sure that computer systems that contain sensitive data are protected from misuse by parties who should not have access to data, leading to increased security costs where sensitive consumer data is held in systems. The addition of privacy to the typology of implementation costs is therefore appropriate.

#### *Health concerns*

The use of RFID has also been hampered amid fears that an overload of radio emissions at higher

power levels puts human health at risks. However, while our respondents were very concerned about tackling privacy issues, they were dismissive of problems associated with health concerns: *“To our knowledge there is no published body of evidence that links radio frequency to human health... because there’s such a severe limit on the wattage and the output of the readers the amount of radio frequency is so small that we don’t think there is an issue... When a fork-lift driver puts a pallet through a couple of readers by a dock door, the output... may be one watt of power”* (EPCA).

Moreover, low cost passive RFID tags, which are likely to be the most common type of RFID tags in use, do not radiate RF energy, they reflect it. Their use should not, therefore, add significantly to background levels of RF energy and will, in any case, contribute less than a number of other devices, including cell phones. *“The health risks are not a prime concern. The power used for RFID tags is much lower [than mobile phone and microwaves] so if the GSM phone is not explicitly considered dangerous then RFID tags or readers are in a completely different category”* (SV2).

## CONCLUSIONS

This study asked two questions about the adoption of RFID in supply networks:

1. Which of the generic interorganizational process innovation costs identified by Bunduchi and Smart’s (forthcoming) generic framework apply to the adoption of RFID applications in supply networks?
2. What, if any, are the influences of these different costs on the adoption of RFID within supply network settings?

The analysis has considered the different forms of costs that can arise in the generation, acceptance and implementation of RFID within supply network settings, and has demonstrated that there is evidence for many of the categories of costs identified in Bunduchi and Smart’s (forthcoming) frameworks of innovation costs. From the evidence available it is apparent that development, switching, implementation and ethical costs and the cost of capital all influence the adoption of RFID technologies in supply network settings during the early stages of technology evolution. Consequently, the costs associated with adoption should be included as dependent variables in a model of process innovation adoption. The results are summarised in Table 3.

Table 3. Summary of results

Costs	Observed influence on adoption
Internal Development	Largely in Auto-ID lab
External Development	Large organizations driving effort (retailers and suppliers)
Initiation costs	
Switching – compatibility costs	Current RFID with future RFID RFID with existing technologies

Capital – technological uncertainty	Immature technology – ongoing development Data accuracy
Capital – market uncertainty	No killer application
Implementation costs - direct	Evidence of significant influence
Implementation costs - indirect	Little evidence - pilot stage technology?
Relational costs - trust	No evidence (pilot stage technology?)
Ethical costs - privacy	Activists groups causing withdrawal/scaling down of pilot studies
Ethical costs - health	Considered, but no evidence of influence

There is evidence that some types of cost had a greater influence than others in influencing early adopters of RFID track and trace technologies in supply networks. For example, the evidence for relational costs was weak, which may be a consequence of the fact that when this work was carried out the majority of projects were taking place within single organizations or were pilot studies. As RFID is rolled out across supply networks it will be important to reassess whether relational costs have grown in importance and the extent to which they influence the likelihood and nature of adoption. Bunduchi and Smart (forthcoming) suggest that the magnitude of the different costs might vary depending on the innovation life cycle. Our study provides some limited evidence to support this argument. During the early stages of RFID adoption, development and ethical costs and the cost of capital seemed to predominate. Implementation costs are likely to become more evident as adoption moves from pilot studies to implementation across a wide range of network players, and from early adopters to more general adoption. Future research is required to explore this argument further.

We need to take into consideration the fact that our study focused on the early development stages of RFID technologies and that the adopters analysed here represent lead users and early adopters. In making any claims of generalisation, we need to acknowledge that these types of user organisations are characterised by different innovation adoption behaviours (Rogers 2003). Therefore, we could expect that for other technologies in the early development stages the pattern of innovation costs encountered during adoption might be similar, but this pattern might change as the technology becomes adopted by the majority of users, and by laggards (Rogers 2003). For example, initiation costs are likely to become more evident as the technology evolves and the majority of users become involved in the adoption of RFID. For these users it is also likely that development costs will play a less significant role.

Although not explicitly considered by this study, there is some evidence that the nature of the different costs accrued by organizations in shaping the adoption of innovation may be dependent on the position of the organization in the supply network, and on the stage of adoption or diffusion of the innovation. Thus, development costs have been concentrated in the organizations that have mandated the use of RFID, and in their major suppliers who have the resources to become involved in development activities. Privacy costs are similarly concentrated in the ‘big brand’ organizations (for example Benetton, Marks & Spencer) whose reputation is more likely to be damaged in the eyes of end consumers by adverse publicity. This early finding now needs further research to investigate the relationship between the position in the supply network and the impact of different costs.

Having demonstrated, through the use of an exploratory qualitative study, that a range of adoption costs are relevant in explaining the adoption of RFID, future research is required to develop and test hypotheses that examine (1) the direction of these influences; and (2) the importance of different costs in shaping adoption decisions. For example, for those interviewed in the study, physical investment costs, in particular the cost of tags, were emphasised as the primary criteria in shaping the adoption decision, while lack of trust was seen as less relevant in the current RFID adoption climate. In addition, the current work has not examined in any detail the characteristics of the supply networks in which the adopting organizations are embedded (for example the level of interdependence of buyers and suppliers or the variation in the technological capability of adopting organizations) all of which may have an impact on innovation diffusion. These variables should form part of further studies.

The research has provided evidence for managers of the types of costs that need to be considered in making decisions about the adoption of RFID in supply network settings. The paper provides a counter-balance to the research that has examined the benefits of innovation adoption but which considers cost to be easy to quantify. For academic researchers the framework demonstrates the potential drawbacks of considering cost as a single high level variable in adoption studies and provides a structure within which costs can be considered when examining the interorganizational process innovations that characterize supply network improvements.

This study has concentrated on a single technology, RFID, at one particular point in the innovation diffusion cycle. Further work is required to examine the pattern of adoption costs for other innovations and, as has been indicated earlier, to assess to what extent the accrual of costs is influenced by position in the supply network.

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